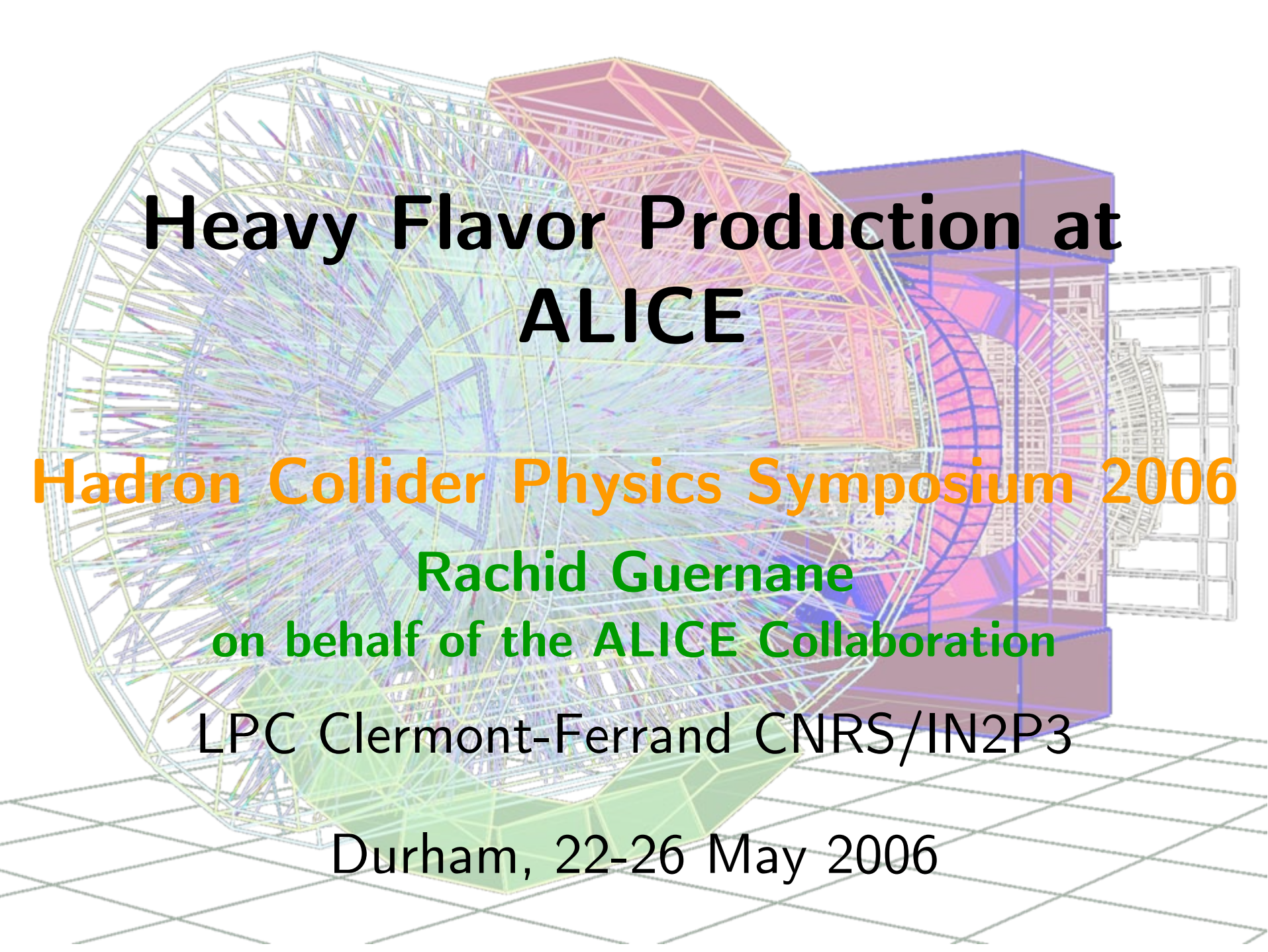


Heavy Flavor Production at ALICE

Hadron Collider Physics Symposium 2006

Rachid Guernane

on behalf of the ALICE Collaboration

LPC Clermont-Ferrand CNRS/IN2P3

Durham, 22-26 May 2006

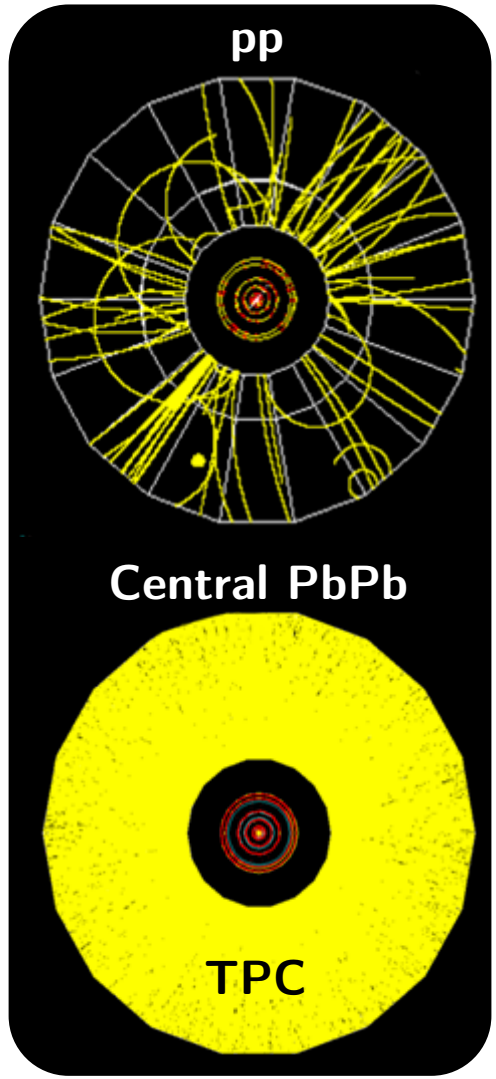
Outline

- Heavy flavor production at the LHC
- The ALICE detector
- ALICE heavy flavor measurements
  - **charm** reconstruction via **hadronic decays**
  - **beauty** detection in **semileptonic** modes
- Summary & outlook

All the material presented hereafter is published in the ALICE "Physics Performance Report", J. Phys. G30 1517-1763 & CERN/LHCC 2005-030

Heavy flavor production at the LHC
Introduction

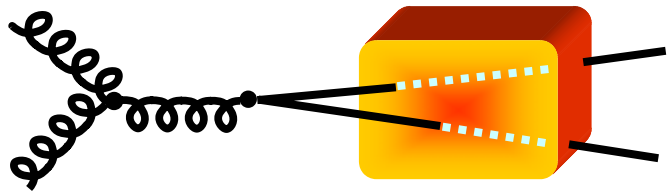
- What for?
  - heavy flavor production in hadron collisions provides a rich QCD phenomenology
    - ! **pp** test reliability of **pertubative calculations**
    - ! **pA** assess **initial state effects**
    - ! **AA** probe the **high colour-density** medium
- LHC's novelties
  - **copious production** of both c & b quarks
  - large inelastic background
    - ! messy environment with **large combinatorics**
      $\propto (dN_{ch}/dy)^2$ **with** $dN_{ch}/dy = 6000$ **in central Pb-Pb!**
- ALICE's plus points (see H-A Gustaffson's talk)
  - **muti-purpose** several heavy flavor measurements within **the same experiment**
  - **precise tracking & vertexing** resolve D's & B's **decay vertices**
  - **PID** π/K separation



Heavy flavor production at the LHC

Hard QCD probes

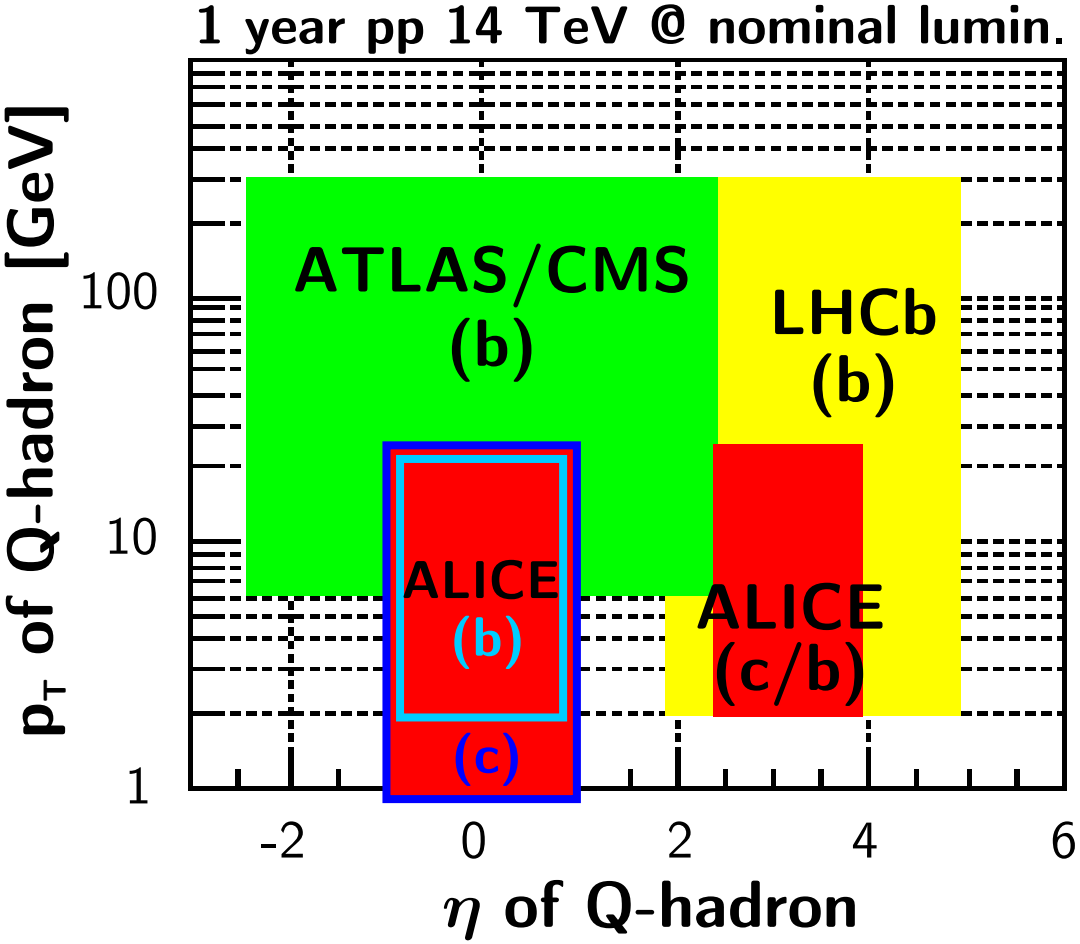
- Sensitive probes of the **collision dynamics**
  - early creation time $\sim 1/m_Q$ (~ 0.1 fm/c $\ll \tau_{QGP} \sim 5 \div 10$ fm/c) & **long lifetime**
    - ! undergo the **whole collision history**



- **Tomographic** probes
  - radiative **parton energy loss** is both color charge & mass dependent
    Phys. Rev. D71 (2005) 054027
    - ! significantly **larger energy loss** is expected for **light q & g** w.r.t ***b* quarks** at the LHC
  - need for a **clean "calibration"**
    - ! **pp** & **pA** experiments provide a compulsory benchmark
- Heavy quark **p_T distribution** sensitive to many competing **nuclear effects**
  - low-p_T (< 6 GeV/c at LHC) region sensitive to **non-perturbative** effects (flow, quark coalescence, gluon shadowing, CGC state...)
  - high-p_T region sensitive to **jet quenching**
- **Complementary** of quarkonia production

Heavy flavor production at the LHC

pp acceptances



Complementarity of the four LHC experiments

HERA-LHC Workshop
CERN-2005-014

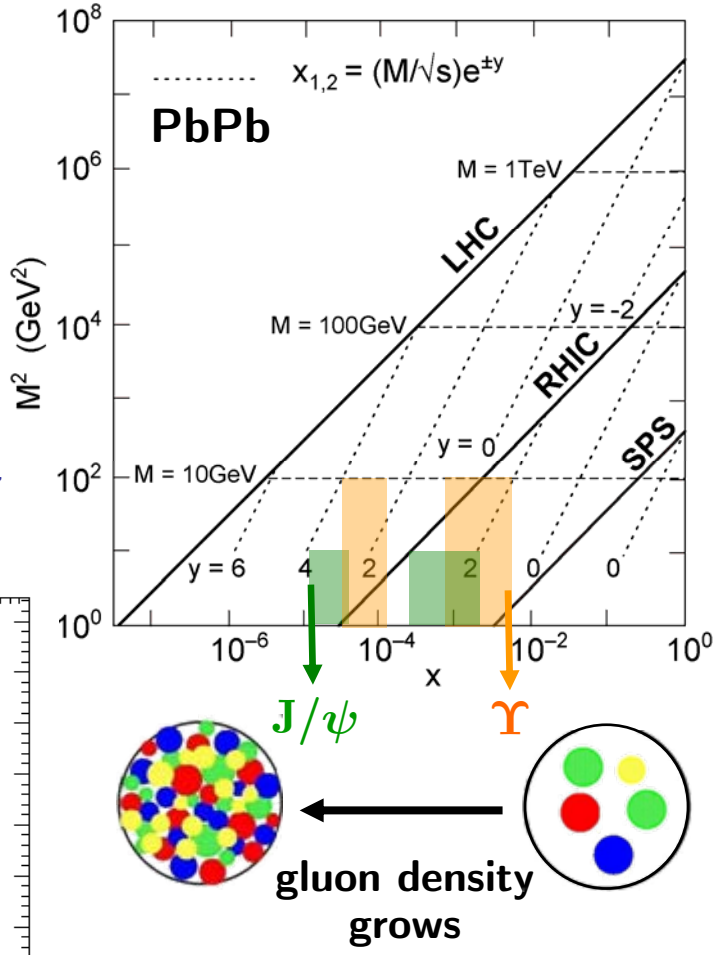
ALICE has acceptance down to very low p_T!

Heavy flavor production at the LHC

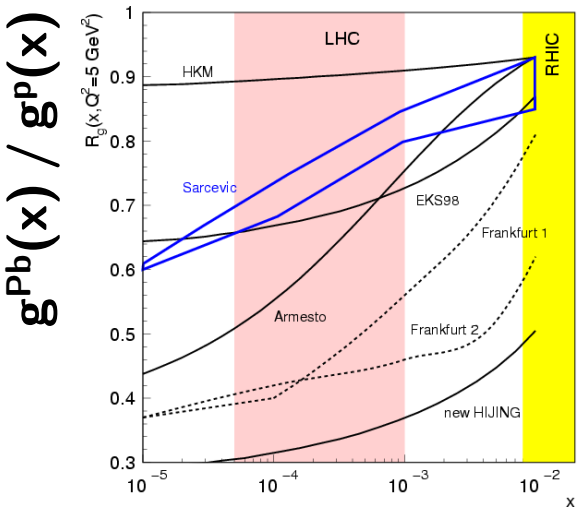
A novel range of accessible x

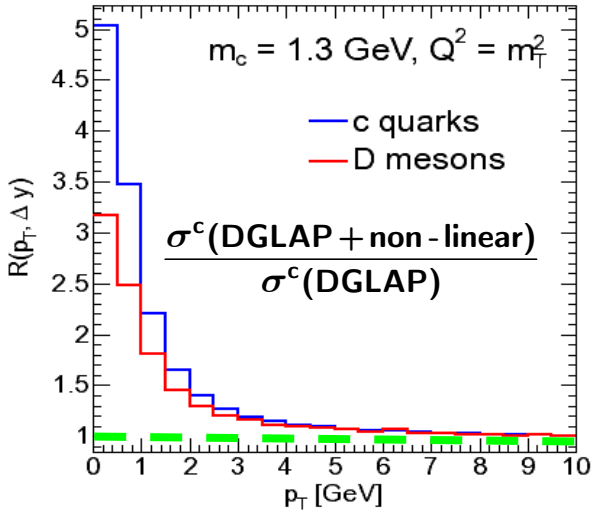
- ALICE probes a continuous range of **x as low as about 10^{-5}** w/ HQs at low p_T and/or forward y
  - **explore QCD** in the new regime of **"small" x** & **"large" Q^2** where a breakdown of the standard collinear factorization approach is expected
    - ❢ deep **nuclear gluon shadowing** at high rapidity in pA
    - ❢ **gluon saturation** at $Q_S^2\,(5.5\,\text{TeV}, \text{Pb}) \sim 10 \div 20\ \text{GeV}^2$
    - ❢ **non-linear terms** in the gluon evolution
      - possible **low-p_T charm enhancement** Phys. Lett. B582 (2004) 157

ALICE kinematic reach



Charm





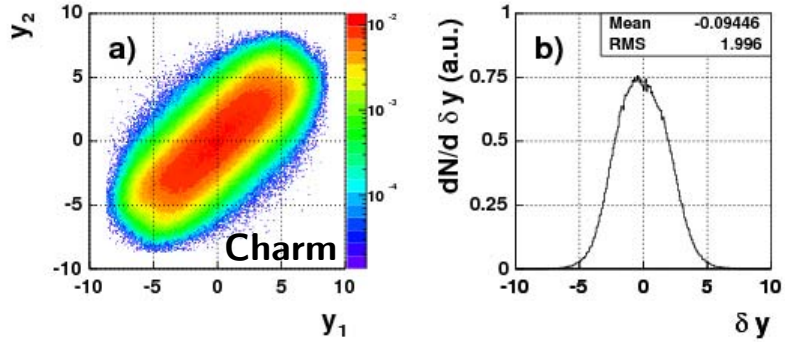
Heavy flavor production at the LHC

Outbreak of large higher order corrections

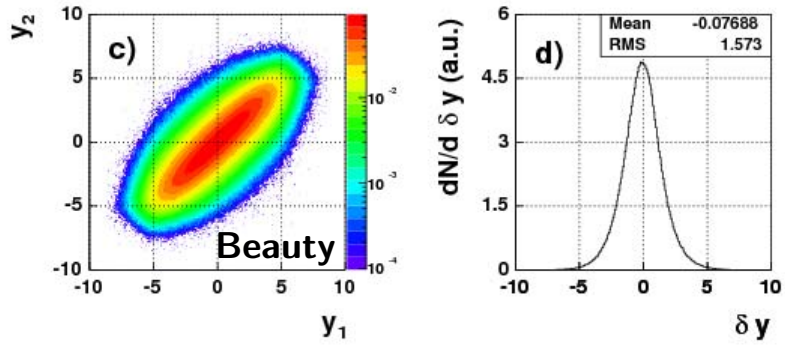
- **LO processes** result in topologies where the Q and the $\bar{Q}$ quarks are produced **back-to-back** and necessarily have **similar p_T**
- **Higher order contributions**
  - can produce much more **complicated topologies**
  - become **dominant at LHC energies**, $K = \sigma_{NLO}/\sigma_{LO} = 1.4 \div 3.2$ for b production [hep-ph/0311048]
  - in the following, heavy quarks have been **generated using PYTHIA (*)**, tuned to reproduce kinematic distributions given by **NLO pQCD** [hep-ph/0311225]

(*) NLO pertubative processes approximated in the PS approach by LO hard scattering (QCD $2 \to 2$ processes) plus initial and final-state cascades

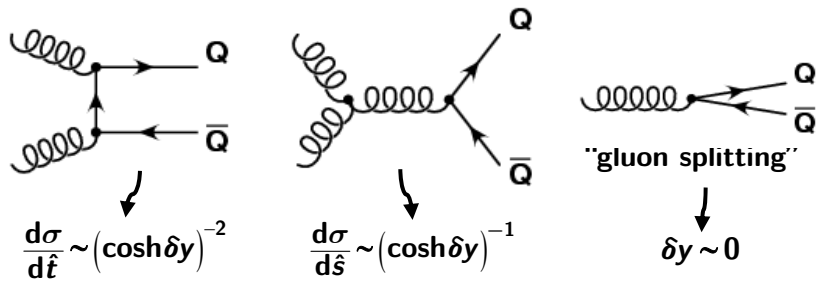
$-4 \leq \eta^{\mu} \leq -2.5$



ALICE muon spectrometer design adapted to **heavy quark detection**



LO graphs **NLO corrections**



Heavy flavor production at the LHC
The ALICE baseline

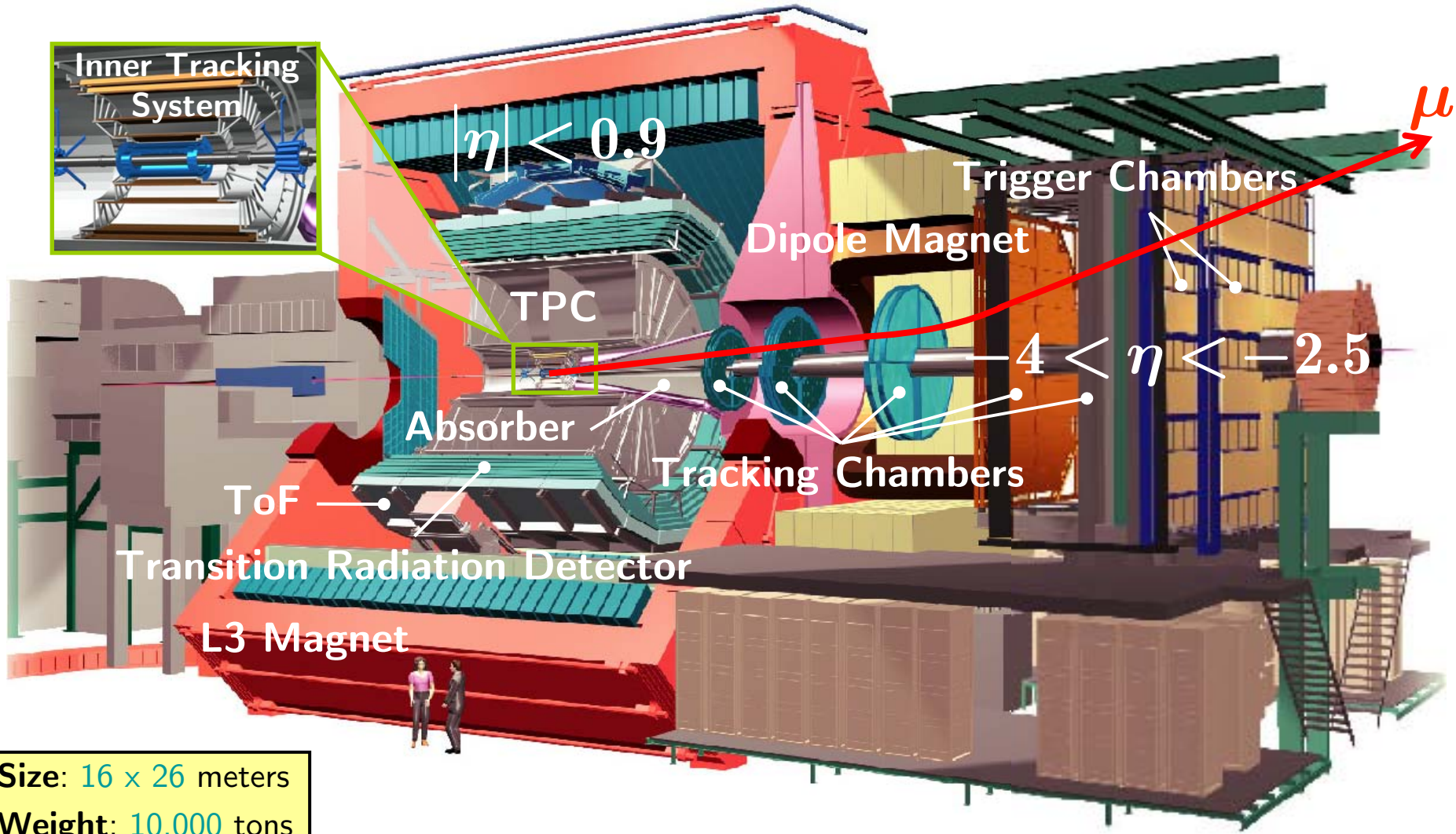
Unpreceding large cross sections!

	PbPb (0-5% centr.) 5.5 TeV		pp 14 TeV	
	charm	**beauty**	**charm**	**beauty**
$\sigma_{Q\bar{Q}}$ (NN) [mb] (*)	6.64	0.21	11.2	0.51
EKS98 shadowing	0.65	0.86		
$N_{Q\bar{Q}}$ per collision	115	4.56	0.16	0.0072

(*) NLO in pQCD calculations from M. Mangano, P. Nason, and G. Ridolfi, Nucl. Phys. B 273 (1992) 295
Theoretical uncertainty of a factor 2-3

The ALICE detector

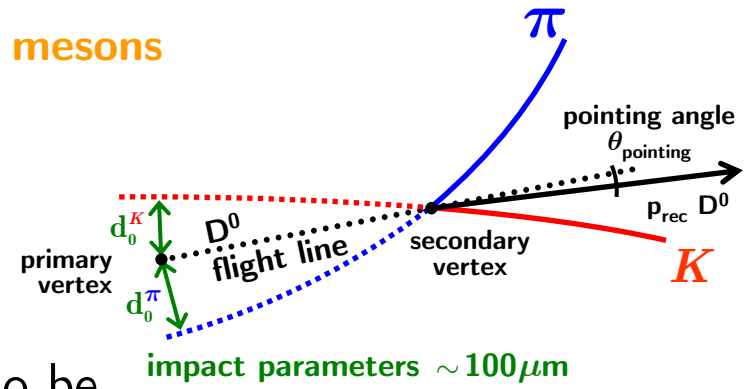
Only dedicated HI experiment at the LHC with a **large suite of detectors** optimized for **high efficiency tracking** and **particle identification** across large range of **momenta** from below **100 MeV** to above **100 GeV**



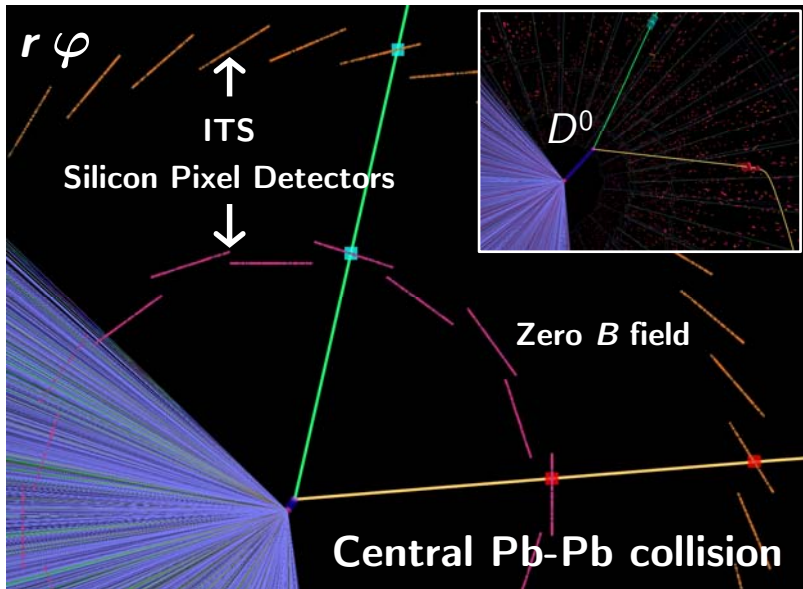
Size: 16 x 26 meters
Weight: 10,000 tons

Direct charm reconstruction in ALICE
The $D^0 \to K^- \pi^+$ "golden" mode

- **Direct measurement** of the charmed meson **p_T distribution**
  - measure the nuclear modification factor **R_{AA} of D mesons**
- **Very challenging** in a heavy-ion environment
  - $S / B \sim 10^{-6}$ in $M_{D^0} \pm 3\,\sigma$ before selection
  - need for a **drastic selection procedure** to reduce the background by **6-7 orders of magnitude!**
- **Secondary production** from ***b*-hadron decays** to be subtracted from direct production



- Detection strategy
  - exploit the **long *c* lifetime** ($c\tau = 124\ \mu$m)
    - ❗ events containing hadronic decays of charmed hadron are selected by requiring
      - two opposite-sign tracks displaced from the primary vertex *i.e.* w/ **large impact parameters d_0**
  - D^0 reconstructed momentum should **point to the primary vertex** ($\theta_{\text{pointing}} \approx 0$)
  - (K,π) **invariant mass analysis** to extract the D^0 yield

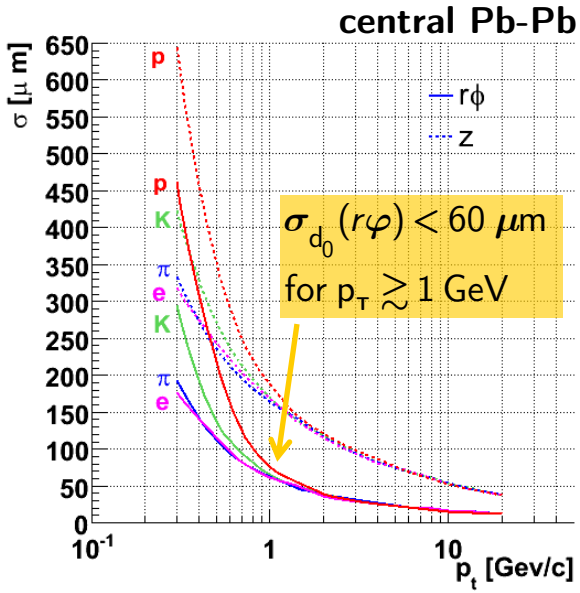


$D^0 \rightarrow K^- \pi^+$

D^0 candidate reconstruction

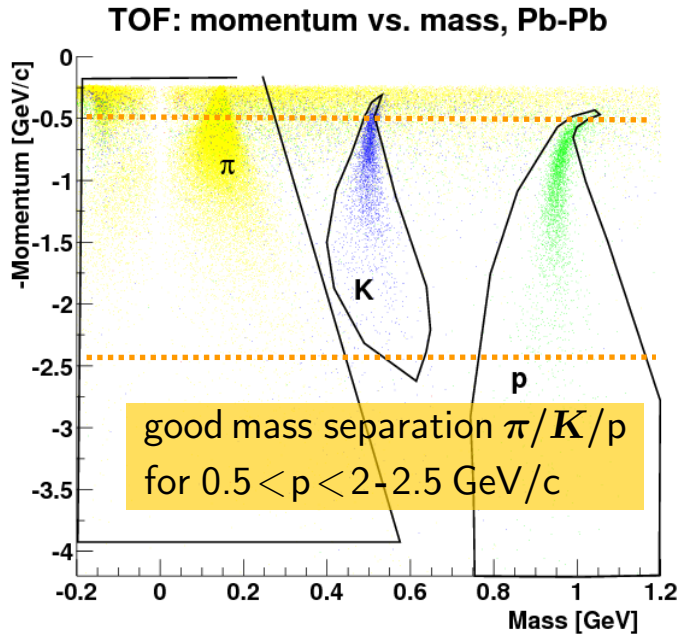
Measurement of the track impact parameter

- track reconstruction in ITS + TPC
- d_0 resolution given by ITS SPD layers



PID

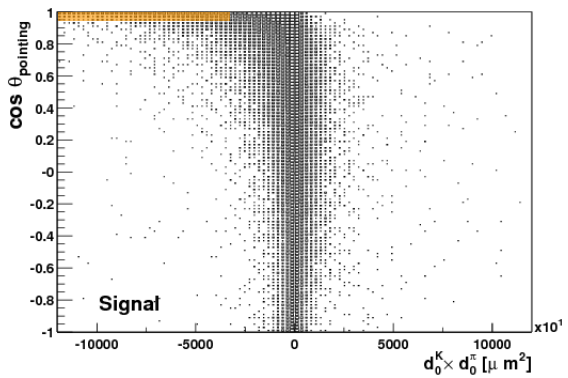
- TOF tag decay products

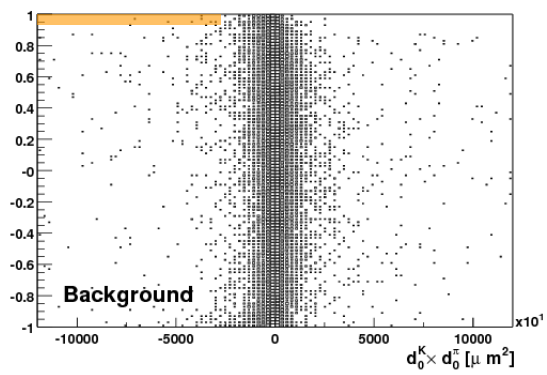


D^0 candidate selection

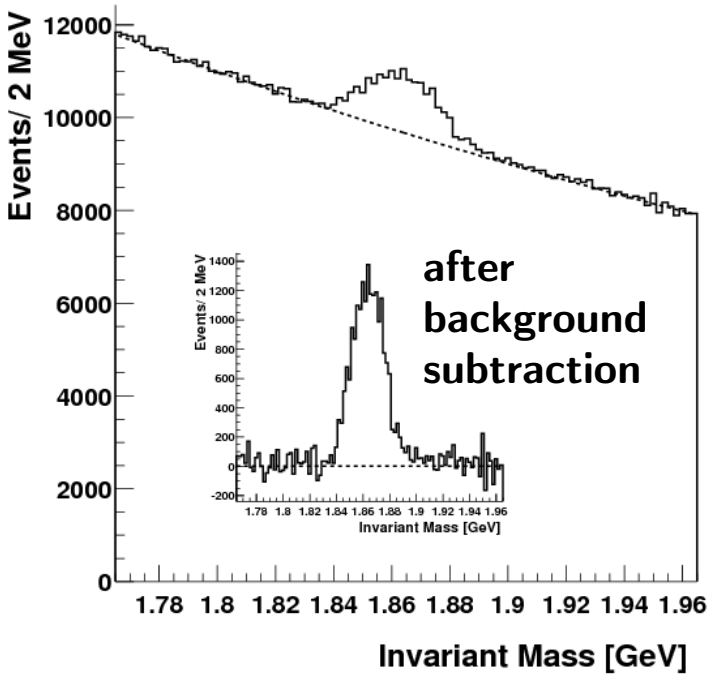
$d_0^K \times d_0^\pi < -40{,}000\ \mu m^2$ & $\cos\theta_{point} \geq 0.98$

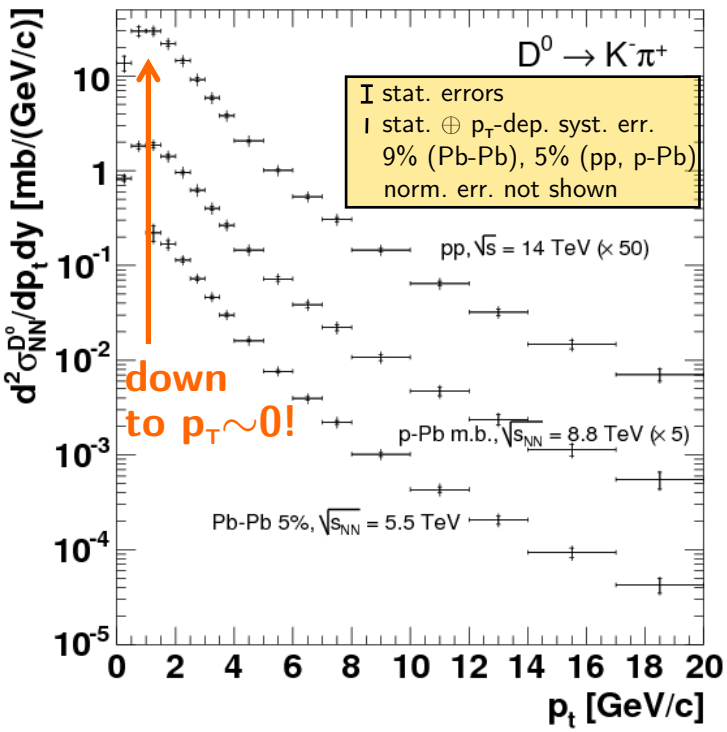
increase S/B by a factor $\sim 10^3$!





$D^0 \to K^- \pi^+$
The results



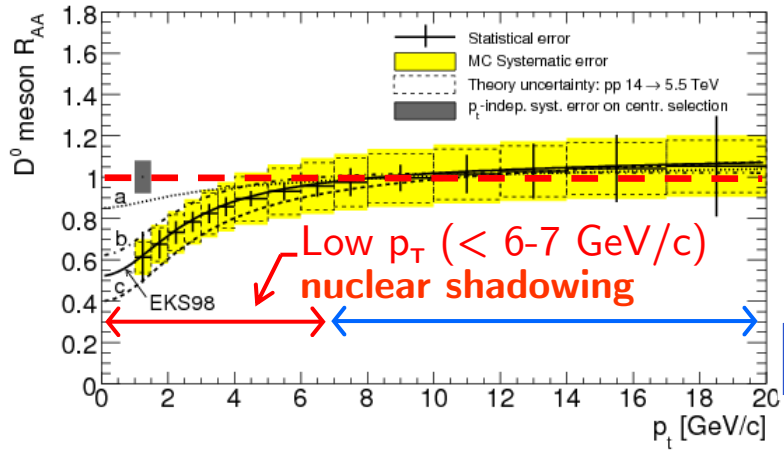


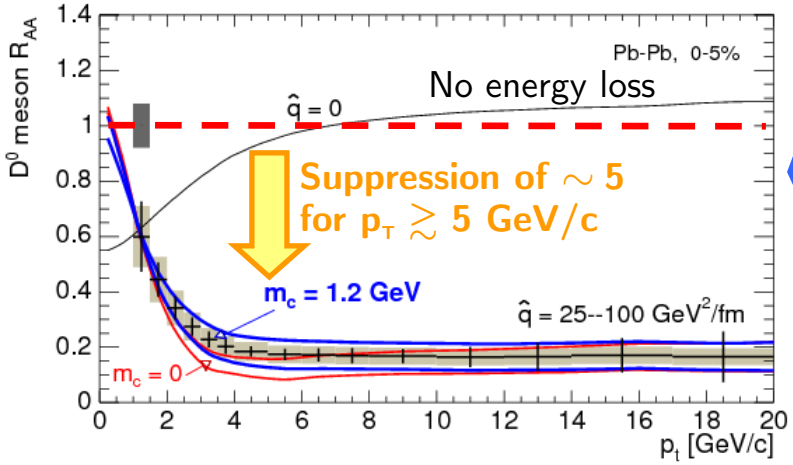
	S/B initial ($M \pm 3\sigma$)	S/B final ($M \pm 1\sigma$)	Significance $S/(S+B)^{1/2}$ ($M \pm 1\sigma$)
Pb-Pb central	$5 \cdot 10^{-6}$	10%	~ 35 (for 10^7 evts, $\sim$1 month)
pPb min. bias	$2 \cdot 10^{-3}$	5%	~ 30 (for 10^8 evts, $\sim$1 month)
pp	$2 \cdot 10^{-3}$	10%	~ 40 (for 10^9 evts, $\sim$7 months)

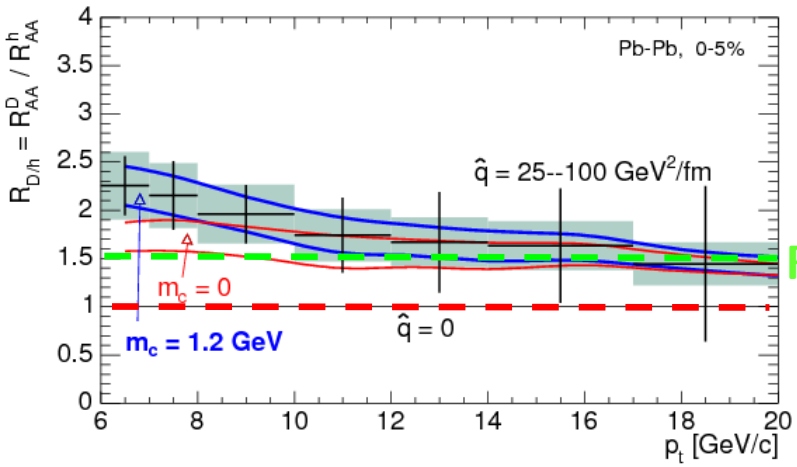
Note

w/ $dN_{ch}/dy = 3000$, S/B larger by $\times 4$ & significance larger by $\times 2$

Perspectives for the study of charm quenching







- The method
  - comparing D^0 mesons p_T distributions in **pp** & **AA**

$$R_{AA} = \frac{1}{N_{coll}} \times \frac{dN_{AA}/dp_T}{dN_{pp}/dp_T}$$

"High" p_T (> 6 - 7 GeV/c)
here **energy loss** can be studied
only expected effect?
in-medium hadronisation...

  - "heavy-to-light" ratio $R_{D/h}$

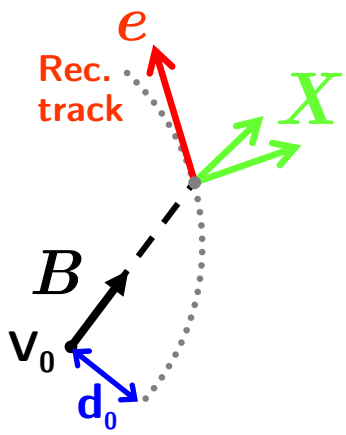
$$R_{D/h}(p_T) = R^D_{AA}(p_T) \,/\, R^h_{AA}(p_T)$$

Test the **color-charge dependence** of QCD energy loss

$R_{D/h} \approx 1.5$

1 year at nominal luminosity
(10^7 central Pb-Pb events, 10^9 pp events)

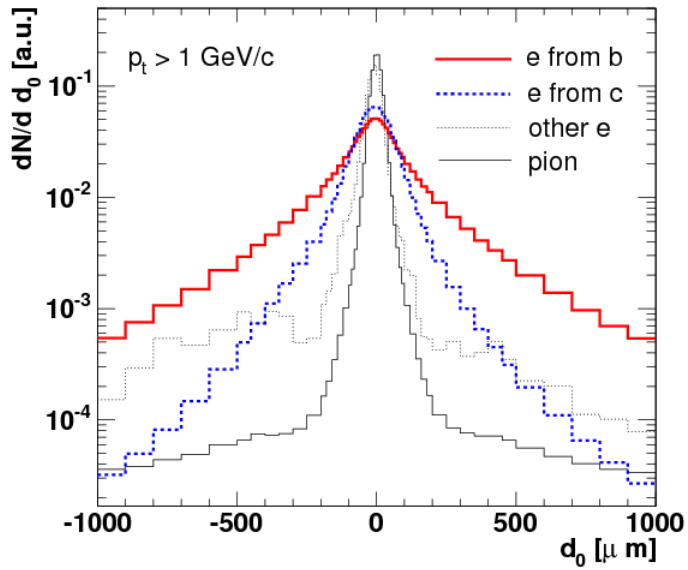
Beauty via single electrons in central Pb-Pb collisions

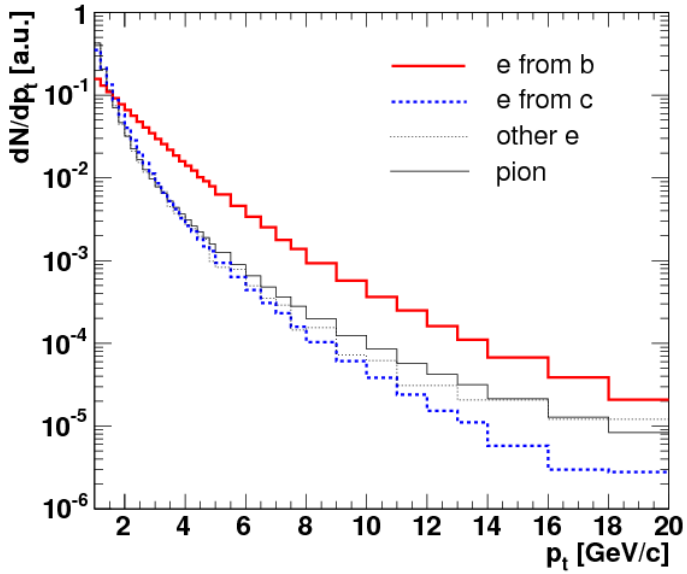


- Main **sources of background**
  - pions misidentified as electrons
  - charm decay electrons
  - Dalitz decays
  - photon conversions
  - strangeness decays

e signal	e backg	π
0.4	$\sim 10^3$	$\sim 10^4$

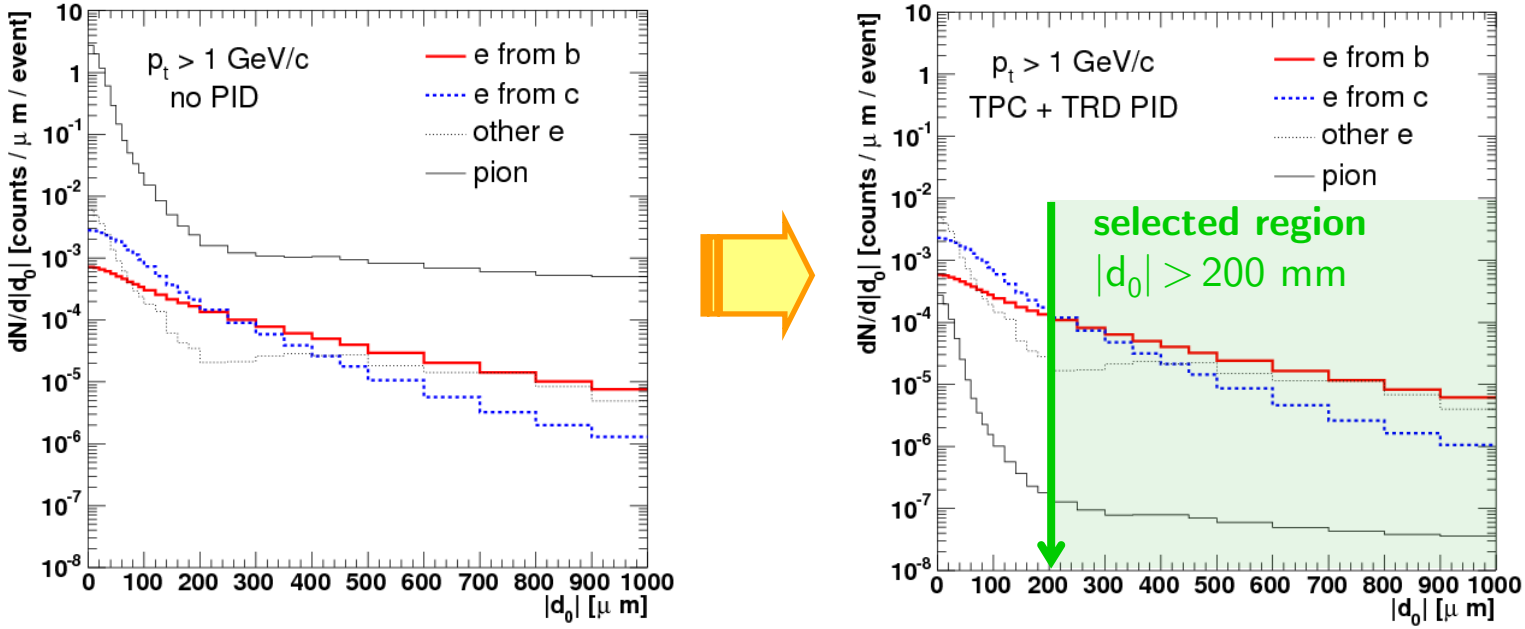
- Detection strategy
  - **electron ID** in TPC + TRD
  - **impact parameter** cut-off
    - B's $c\tau \sim 500\mu$m
  - **p_T** cut-off
    - large b-quark mass $\rightarrow$ hard spectrum





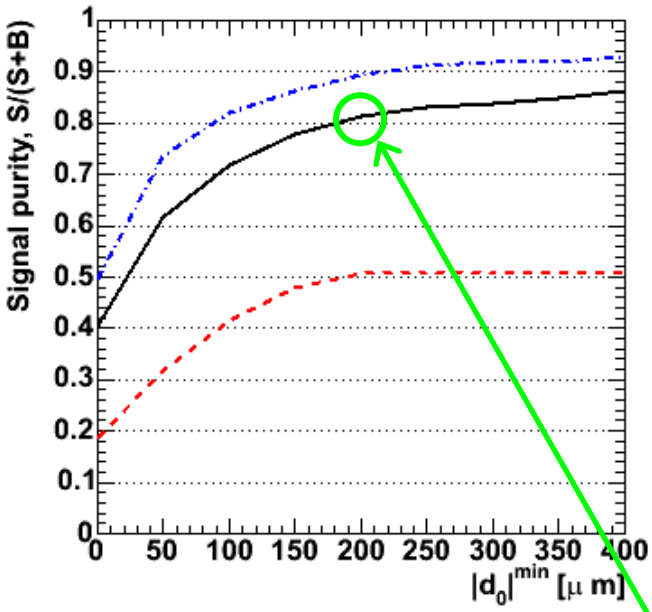
$B \rightarrow e\,X$
e identification in TPC + TRD

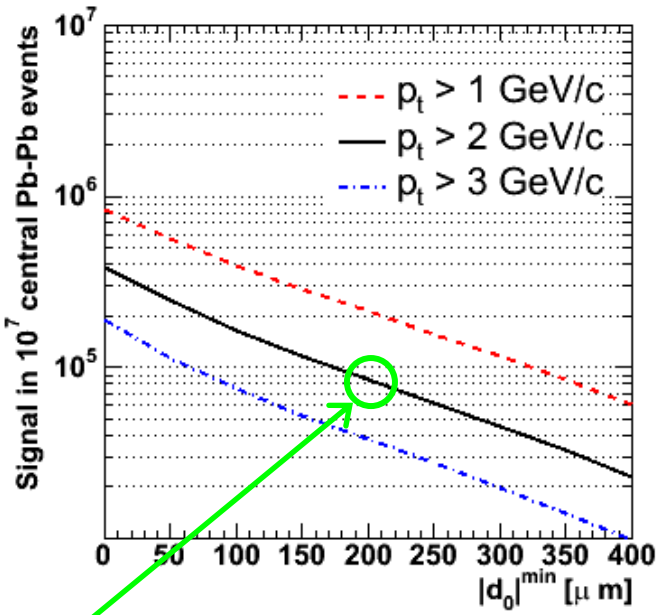
- **Charged pion contamination** reduced by **4 orders of magnitude** after electron ID w/ a combined **dE/dx** and **transition radiation** selection



$B \rightarrow e\,X$
Purity & statistics

- **Signal-to-total ratio** & **expected statistics** in 10^7 central Pb-Pb events



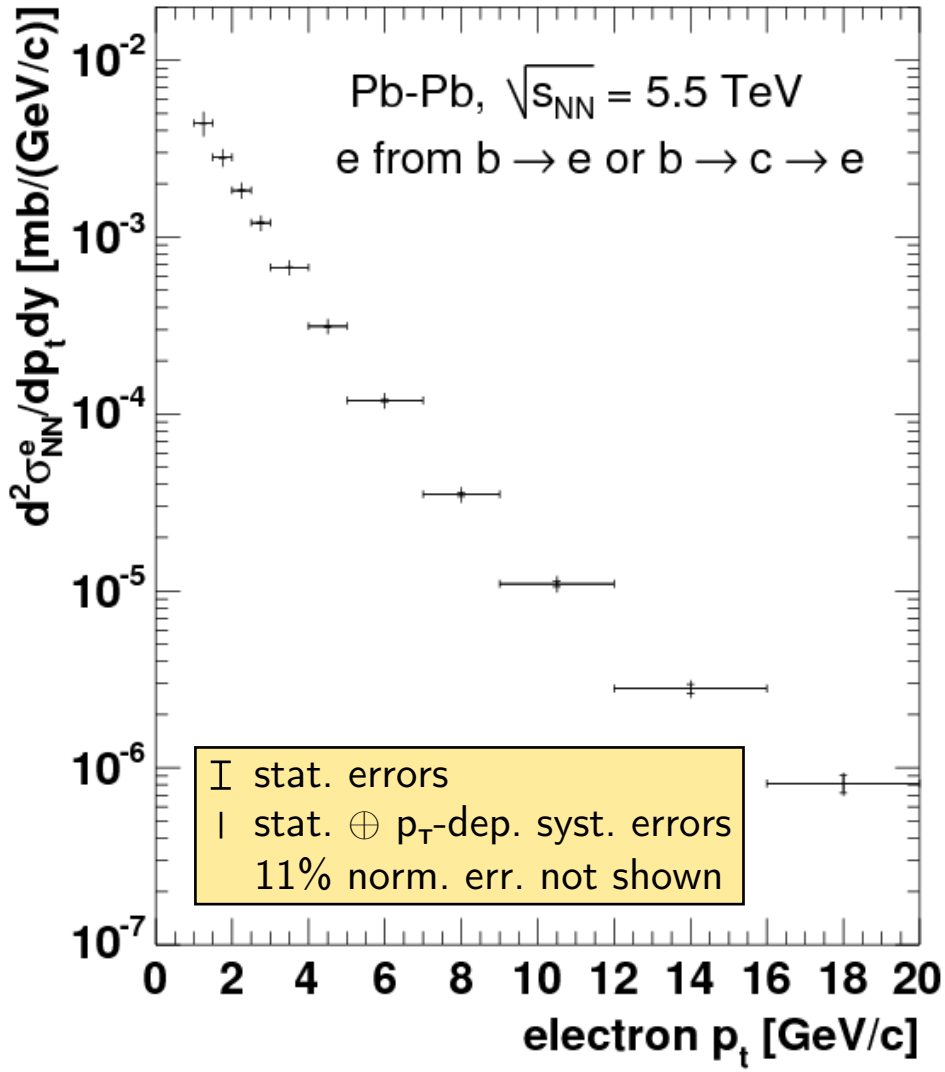


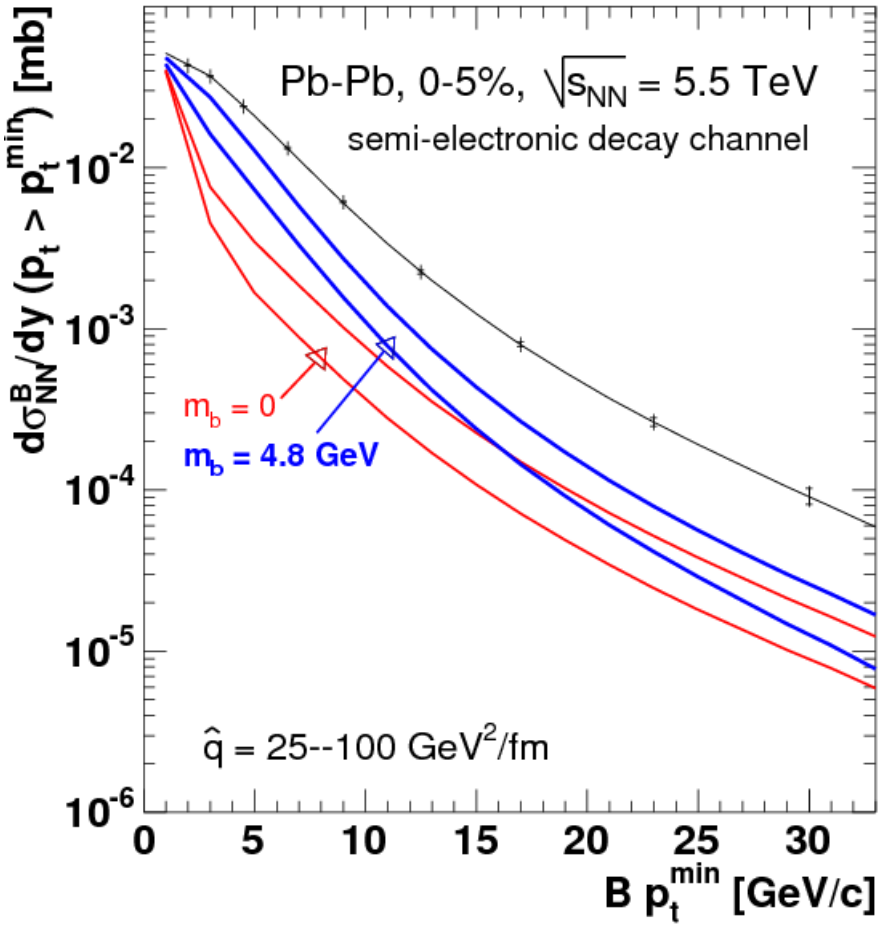
$p_T > 2$ GeV/c & $200 \leq |d_0| \leq 600\,\mu$m

80,000 electrons from B decays with a 80 % purity

$B \rightarrow e\,X$

p_T - differential cross sections

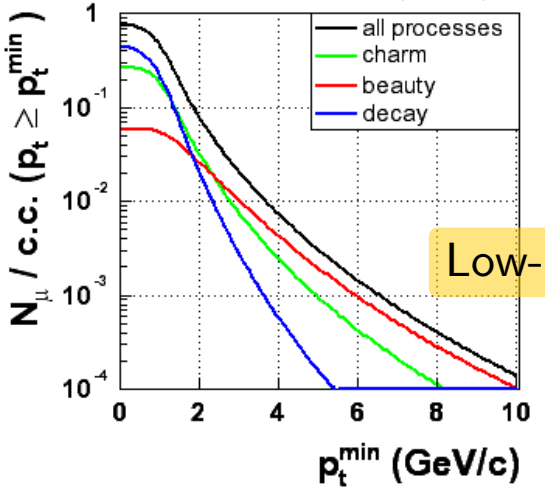




Beauty measurement using muons

- A representative fraction of b-quarks is detected in ALICE through their **semileptonic decays**

5 $b\bar{b}$ pairs / central Pb-Pb collision (5 %)



Low-p_T trigger cut

$$B^+ \to \overline{D^0}\ \ell_1^+ \nu_\ell \hookrightarrow \ell_2^- X'$$

$$\overline{B^0} \to D^+\ \ell_3^- \overline{\nu}_\ell \hookrightarrow \ell_4^+ X''$$

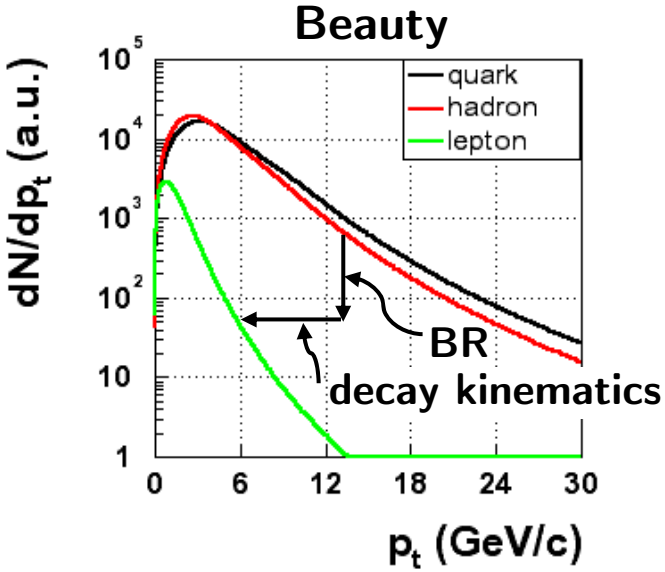
Large BR $\sim$ 10 %

$$B^+ \to \overline{D^0}\ \ell_1^+ \nu_\ell \hookrightarrow \ell_2^- X'$$

$$\overline{B^0} \to B^0 \to D^-\ \ell_3^+ \nu_\ell \hookrightarrow \ell_4^- X''$$

oscillations

correlated LS muon pairs from $b\bar{b}$ decays

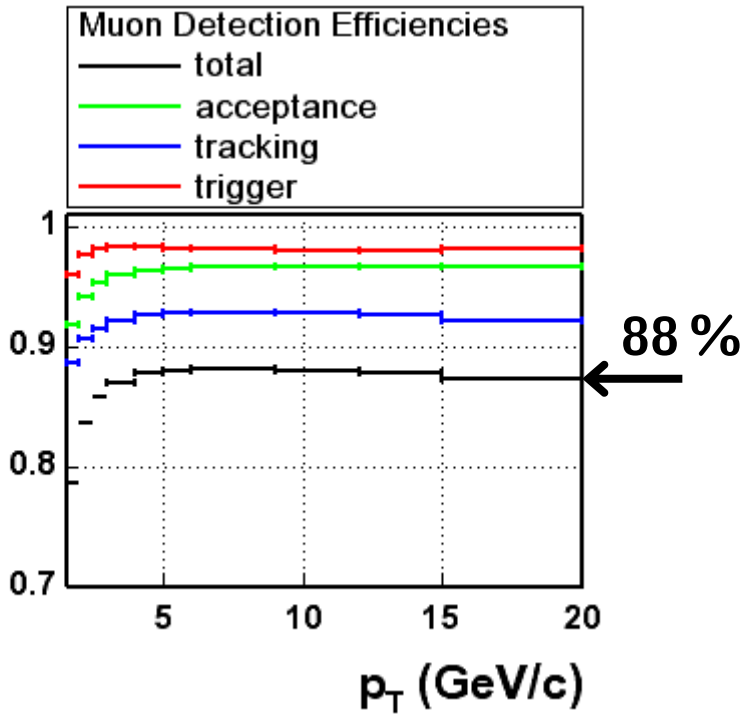


- How to **enhance b signal**
  - muon p_T cut-off $\langle p_T^Q \rangle \sim m_Q$ and **harder fragmentation**

$B \to \mu\ X$
Muon detection

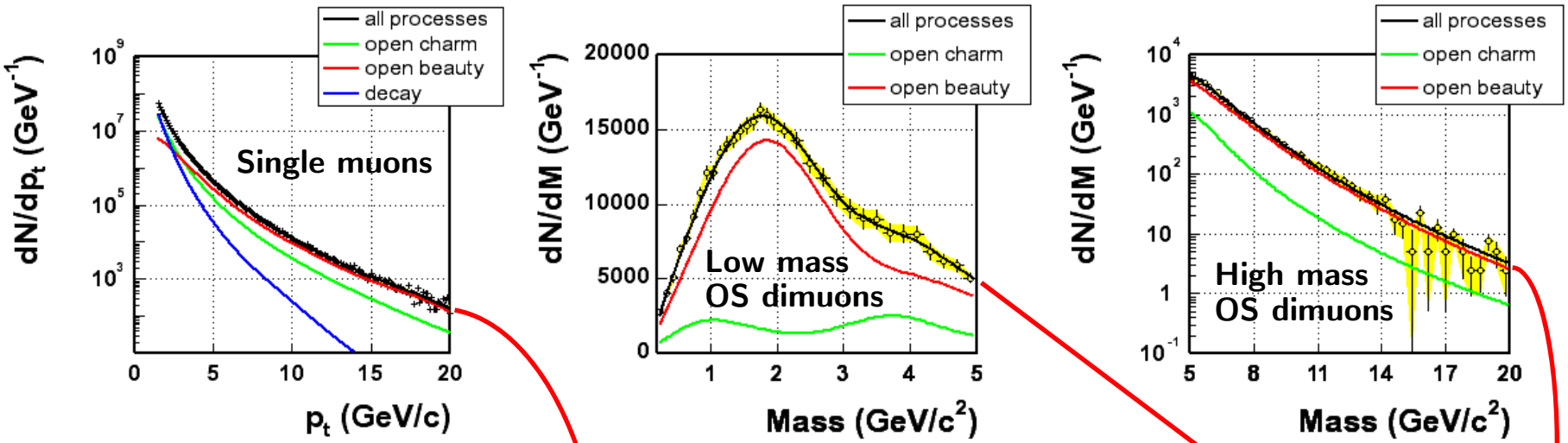
- Muons are **identified** with a **high p resolution $\sim$ 1-2 %** by their ability to **punch through** more than **15 interaction lengths** of materials
- Acceptance $\mathcal{A}_{\text{track}}$ is the fraction of **"trackable tracks"** (1/2 TC1-3, 3/4 TC4-5, 3-4 MT1-2)

	Charm		Beauty		
%	$\mu^{\pm}$	$\mu^{+}\mu^{-}$	$\mu^{\pm}$	$\mu^{+}\mu^{-}$	$\mu^{\pm}\mu^{\pm}$
$\mathcal{A}_{\text{geom}}$	13	3	12	5	3
$\mathcal{A}_{\text{track}}$	42	19	75	46	51
$\varepsilon_{\text{track}}$	27	8	62	29	34
$\varepsilon^{\text{Low}}_{\text{trigger}}$	13	2	53	17	23
$\varepsilon^{\text{High}}_{\text{trigger}}$	4	0.3	29	4	7



$B \rightarrow \mu X$
Muon raw yields

- Uses 3 different **data samples**
- Fits with fixed shapes from the Monte Carlo & **beauty amplitude** as the **only free parameter**



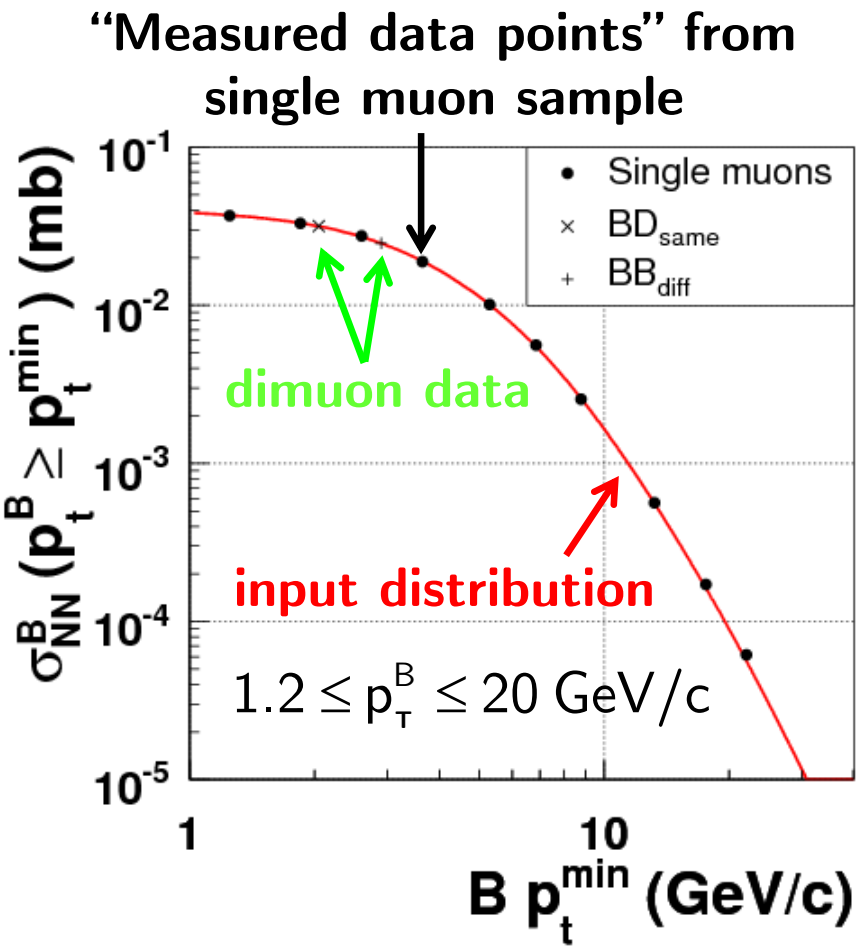
Pb-Pb 0-5 % centrality
$\mathcal{L} = 5 \times 10^{26}$ cm$^{-2} \cdot$ s^{-1},
running time 10^6 s

M [GeV/c^2]	0 - 5	5 - 20
$N_{\mu\mu}$ from $b\bar{b}$	41461 ± 1.91%	6983 ± 1.86%

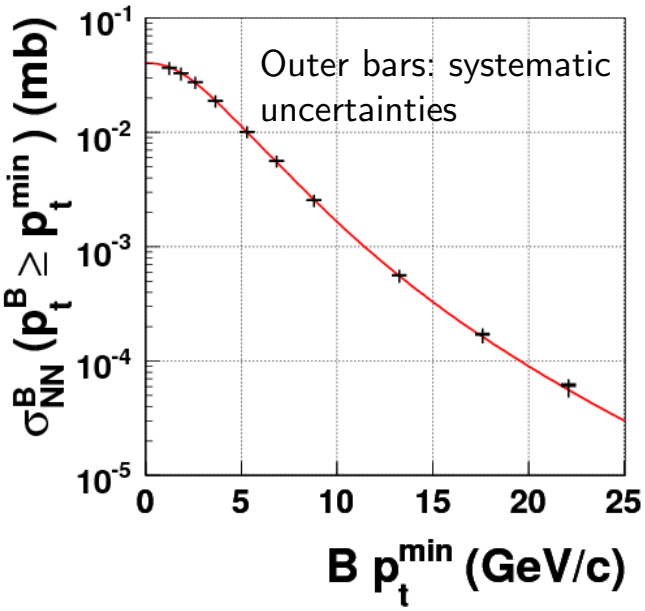
p_T [GeV/c]	1.5 - 2	2 – 2.5	2.5 - 3	3 - 4	4 - 5	5 - 6	6 - 9	9 - 12	12 - 15	15 - 20
N_μ from b	2.2 10^6 ± 0.03%	1.5 10^6 ± 0.04%	0.9 10^6 ± 0.06%	0.9 10^6 ± 0.07%	3.7 10^5 ± 0.13%	1.5 10^5 ± 0.2%	1.2 10^5 ± 0.23%	1.9 10^4 ± 0.6%	4.7 10^3 ± 1.26%	1.8 10^3 ± 2.06%

$B \rightarrow \mu X$

b - meson inclusive cross section

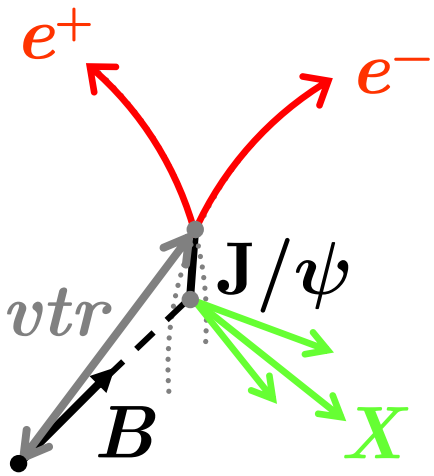


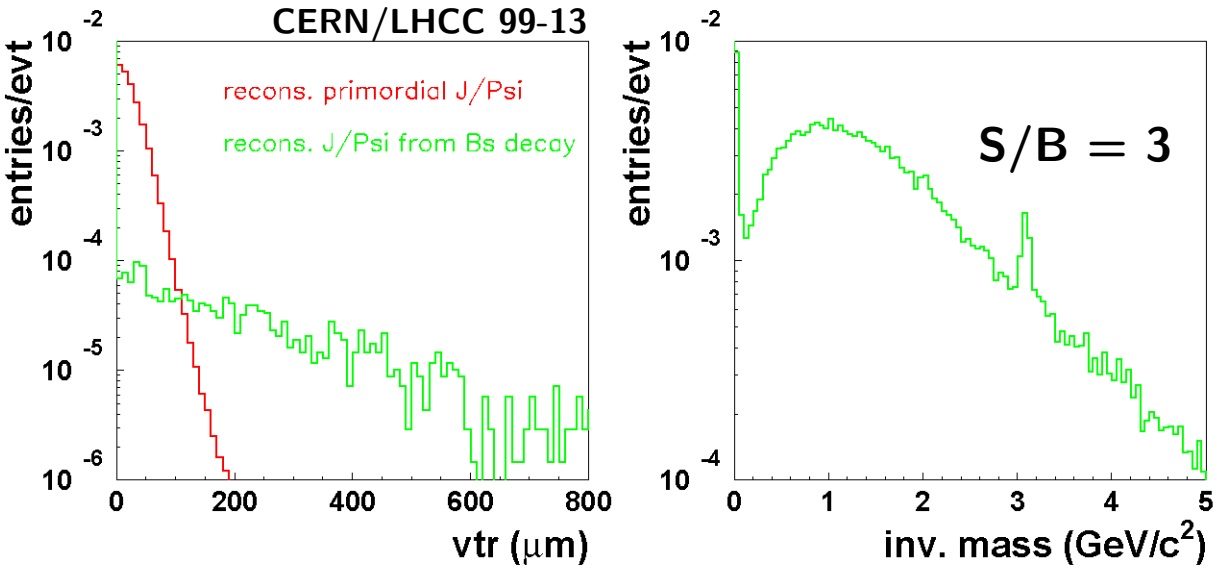
- Beauty inclusive production cross section **measured over a wide p_T region**
- **Any deviation** from pQCD scaled pp measurement could indicate **effects from dense medium!**



Measuring beauty production using secondary J/ψ from b-hadron decays

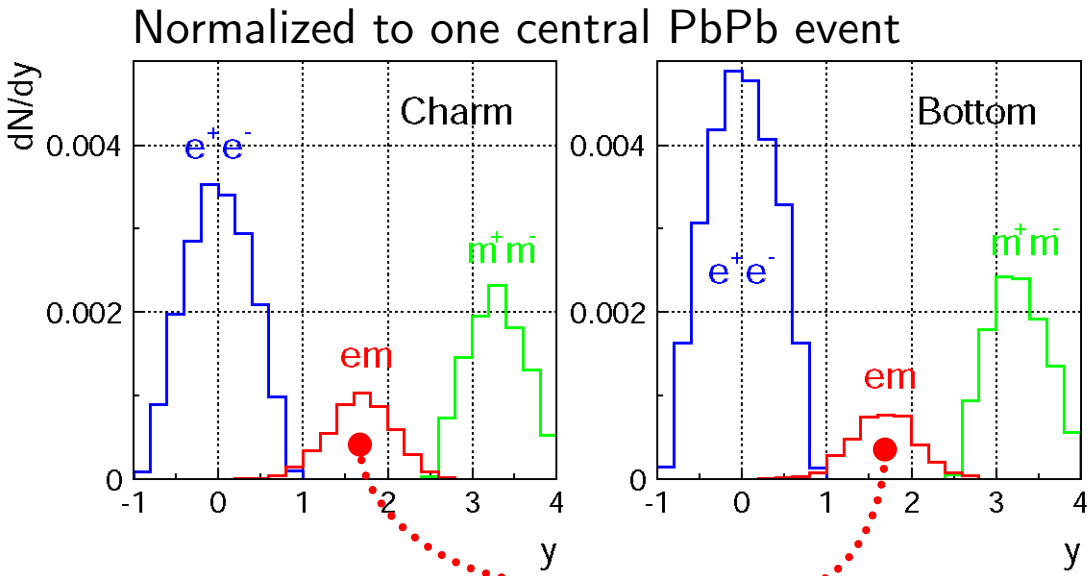
- $b \to \mathrm{J}/\psi\,(1\mathrm{S})$ anything
  BR = **1.16 ± 0.10%** (from PDG)
- N($b \to \mathrm{J}/\psi$) / N(prompt J/ψ) = **30 %**
- Needed to be disentangled for **QGP direct J/ψ suppression** signature
- Also sensitive to ***b*-quark quenching**

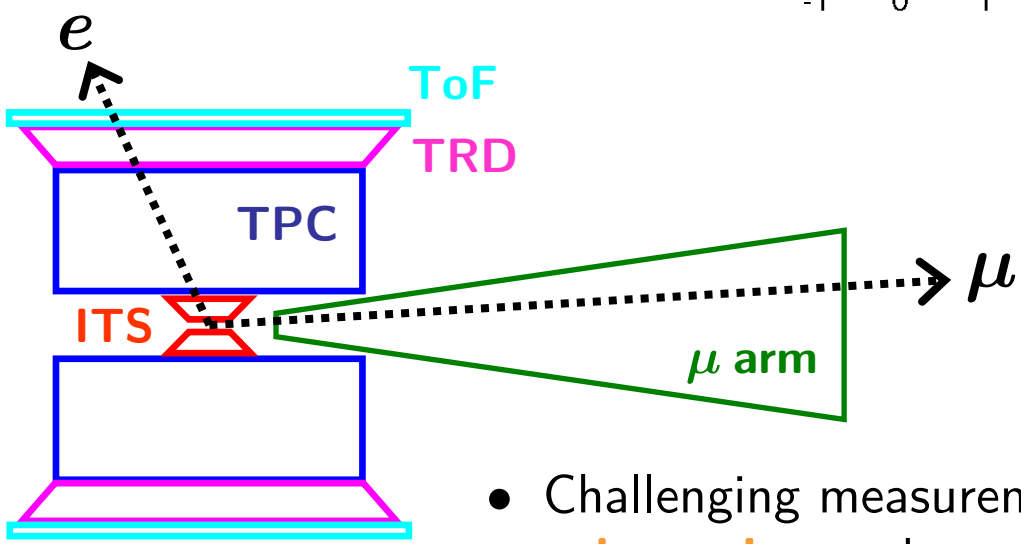




Measuring beauty production using $e\mu$ coincidences

- $e\mu$ channel provides an **independent estimation** of b production cross section with large statistics **$\sim$ 2000 pairs/y** w/ **$p_T > 2.5$ GeV/c** [ALICE-INT-2000-01]



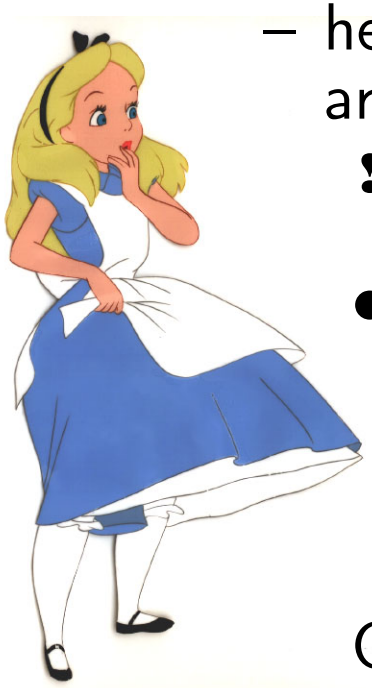


Intermediate **rapidity coverage** of $e\mu$ pairs

- Challenging measurement due to **background subtraction** and **rescattering effects**

Summary & outlook

- ALICE despite "non-dedicated" has a full heavy flavor physics program
  - **large available statistics** of both hadronic & semileptonic heavy flavor decays reconstructed w/ high **tracking efficiency** & **resolution** and good **particle identification**
  - heavy flavored hadron production **cross sections** are assessed w/ **small errors**
    - ! open promising perspectives for the study of **heavy quark quenching**
    - ...and more to come
      - muon pair **correlations**, a powerful probe of **higher orders**
      - **multi-muon** events in **pp** & **pA**
      - ALICE ***b*-tagging** capabilities with soft electrons



Get ready for **first pp runs!**